

Carbon Deposition and Removal on Mo/Si Mirrors

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INTRODUCTION

In the Engineering Test Stand (ETS) , an advanced lithography tool being developed in the EUVL (Extreme Ultraviolet Lithography) Program, multilayer mirror (MLM) surfaces must be kept as clean as possible during tool operation to maintain processing throughput. Carbon contamination of MLMs can reduce mirror reflectivities and wafer throughput. This contamination can be produced by the EUV-created photoelectron cracking of hydrocarbon (HC) vapors adsorbed on MLM surfaces by EUV radiation, and has been previously observed^{1,2} on HC+EUV-exposed optics. During 2000, on Beamline 12.0.1.2 we conducted a series of experiments to measure both the deposition of carbon on Mo/Si MLM samples and its removal using molecular oxygen + EUV radiation. This work was performed to help determine the utility of molecular oxygen as a cleaning agent in ETS.

EXPERIMENTAL PROCEDURE

All experimental runs were performed using a removable, ultrahigh vacuum (UHV) chamber that could be attached to a port on the existing EUV Interferometry chamber on Beamline 12.0.1.2. This chamber had a movable aperture located at the EUV beam crossover point downstream from the Interferometry chamber. This aperture provided vacuum isolation from the upstream beamline, permitting exposure pressures up to $\sim 10^{-3}$ Torr to be used in the MLM chamber. The chamber itself was described in more detail in a previous ALS Compendium Abstract³. In this chamber the following measurements were taken: *in-situ* EUV reflectance of the MLM under test, photoemission from the MLM, and measurement of the total and partial gas pressures using an ion gauge and quadrupole residual gas analyzer (RGA). Auger Electron Spectroscopy (AES) sputter-through depth profiling was used to determine near-surface composition-depth profiles in all MLM samples. In a typical experimental run, one MLM sample with dimensions ~ 1 cm x 3 cm was used, and about 10 carbon spot-exposure regions were put onto each sample. EUV powers (at 92.3 eV) used in this work ranged from ~ 0.2 mW/mm² to ~ 4 mW/mm². Oxygen partial pressures were varied from about 10^{-6} Torr to 5×10^{-4} Torr. The HC vapor pressure in these experiments was about 1000 times greater than expected in ETS, a condition chosen so that experiments could be completed within available beamtimes

During the carbon deposition/removal work, two types of experiments were performed using Mo/Si multilayer mirrors (40 bilayer pairs, Si capping layer, maximum initial peak reflectivity of ~ 67 % at 92.3 eV):

- (1) "Deposit-remove" experiments, in which carbon spots were deposited by the combination of HC vapor + EUV. The spots were then removed by shutting off the HC source and admitting molecular oxygen. Most experiments were conducted this way.
- (2) "Coexposure" experiments, where HC vapors + molecular oxygen were admitted simultaneously into the test chamber in the presence of EUV light and the resulting retardation of carbon buildup was measured.

In addition to measuring the carbon deposition/removal rates using these techniques, any oxidation of the MLMs resulting from the EUV+oxygen exposure was determined both by the *in-situ* techniques and the AES sputter profiling.

RESULTS

At a constant HC partial pressure (corresponding to 55 AMU in the HC RGA spectrum of $\sim 2 \times 10^{-9}$) carbon (C) deposition increased with increasing power. The relative reflectance (reflectance/ original reflectance) of the MLM as a function of EUV power and exposure time is shown in Figure 1 below. No drop in reflectance was observed when the MLM was exposed to ambient background gases. However, with the addition of hydrocarbon vapors, mirror reflectivities dropped due to carbon buildup. Although the reflectivity reduction appeared to be exponential with time, close examination of the data revealed that superimposed on the exponential decrease there is an oscillatory behavior, which is possibly due to reflectivity interference effects occurring in the growing C layer. The presence of these carbon layers was verified by the AES profiling, and showed that C deposition rates as high as ~ 5 nm/hr could be achieved at the highest EUV power.

The "deposit-clean" experiments showed that C spots could be completely removed by exposure to EUV+oxygen. Each C spot was deposited until the mirror reflectance was reduced by $\sim 4\%$ (i.e., $R/R_0 \sim 0.96$). After the HC vapor was removed, oxygen was introduced at different pressures together with different EUV powers and the approximate C removal rate was measured. The results from these experiments are shown in Figure 2. As the data show, the removal rate increases with both EUV power and with oxygen pressure. However, the dependence of the removal rate on these quantities is nonlinear and increasing the oxygen pressure influences the C removal rate more than a similar increase in the EUV power for the oxygen pressure and EUV power ranges studied.

Coexposure experiments, where HC vapors and oxygen are present simultaneously with EUV light impinging on the MLM, have been started. The data show that an oxygen pressure of 5×10^{-4} Torr completely prevents C buildup at a EUV power of about 0.4 mW/mm^2 , while a pressure of 5×10^{-5} Torr only reduces the C deposition rate. More experiments are underway to explore this type of cleaning.

AES profiling has determined that exposure of a MLM to molecular oxygen at pressures of 5×10^{-5} Torr at EUV powers of $\sim 3 \text{ mW/mm}^2$ for 8 hours resulted in a growth of an additional 0.3 nm of SiO_2 at the MLM surface. These results are encouraging in light of the fact that HC contamination levels used in this experiment were about 1000x measured in ETS and that oxygen substantially pressures lower than 5×10^{-5} Torr would probably be required to stop C buildup from such HC vapors. However, experiments with longer exposure times than currently possible on the beamline would be necessary to determine if oxygen is indeed not a practical oxidation threat to the Mo/Si MLM mirrors in ETS.

SUMMARY

EUV-promoted carbon deposition and removal rates have been measured when a MLM is exposed to HC vapors or molecular oxygen. The data acquired in this work on beamline 12.0.1.2 will be directly applied to the use of molecular oxygen in ETS as a means for reducing HC-

caused buildup on the MLM optical elements. Oxidation of the Mo/Si MLMs appears to be small but requires additional study to be better characterized.

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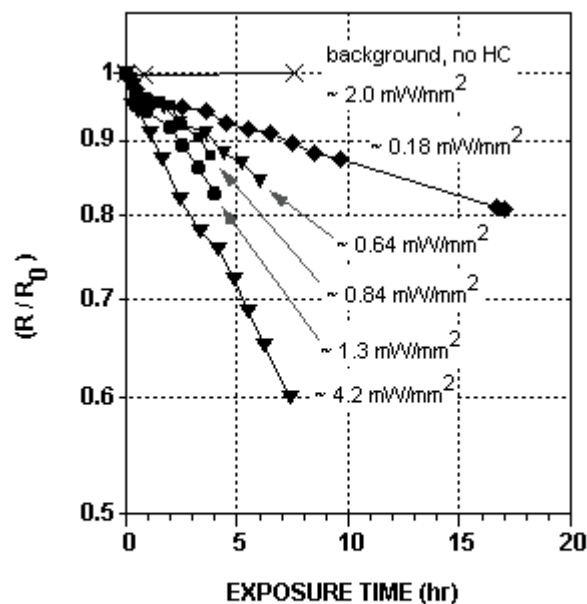


Figure1. Relative reflectance (reflectance/ original reflectance) of Mo/Si MLM exposed to HC vapors as a function of EUV (92.3 eV) power.

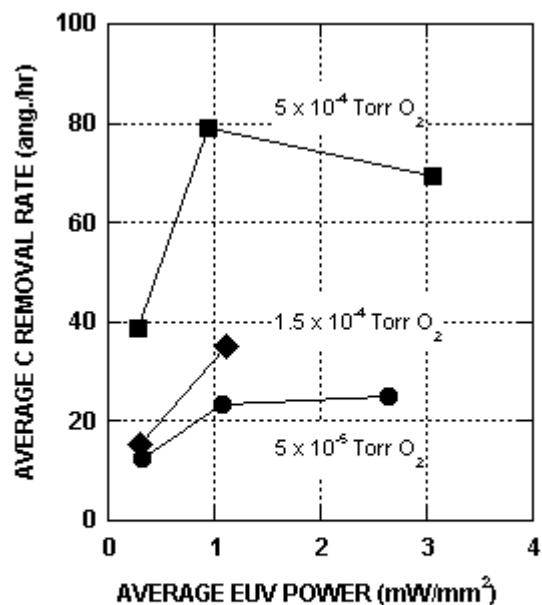


Figure 2. Average C removal rates as a function of molecular oxygen pressure and average EUV (92.3eV) power.